Low-Threshold Digital Educational Escape Rooms Based on 360VR and Web-Based Forms

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Abstract: Escape rooms are an established game genre that has become popular in educational contexts in recent years. Digital escape rooms are variations, which use digital environments and may be played by participants not present on site. Compared to physical escape rooms, digital escape rooms are characterised by lower implementation and application efforts and at the same time by reduced intensity of the experiences. There is little evidence to date as to whether these low-threshold escape rooms are nevertheless sufficiently effective for learning. In this evaluation study, a learning activity based on a digital educational escape room (DEER) that uses the 360°-based spatial visualization (360VR) of a waterworks and a web-based form – contributing guidance and the escape room-specific challenges – is analysed. In the learning activity, students of environmental engineering study programs are asked to explore the 360VR-based waterworks guided by the instructions and challenges in the web-based form. Quantitative results of the study on learning outcomes and variables relevant to learning, such as emotion, motivation, and usability (N=73) are reported. The evaluation is supported by the qualitative results of guided interviews. Remarkably, some participants would have preferred to explore the 360VR environment without the guidance provided by the web-based form. Overall, the results show the learning effectiveness of the DEER, the efficacy of the web-based form as a guidance instrument, and values of learning-relevant variables that are conducive to learning. The DEER also achieved a high level of acceptance among students. Due to the low effort required for the creation of the DEER by lecturers and for application on the part of students, the presented combination of 360VR and web-based forms can be seen as a powerful low-threshold learning tool that enriches teaching.

Keywords: 360-degree, Virtual field trip, Virtual reality, Higher education, Motivation, Field trip, 360VR

1. Introduction

Escape rooms are described as puzzle games played with a time limit in a locked room of the real world by a team (Hall, 2021). The challenge to escape a physically locked room in which puzzles must be overcome under time pressure in a group and within a narrative creates highly immersive experiences (Anton and Pakhalov, 2022) that encourage many escape room visitors to repeat such experiences and that have led to strong growth in the number of escape room facilities in recent years (Spira, 2020). Like many games, escape rooms are also applicable in education (Ratan and Ritterfeld, 2009). While escape rooms were originally tied to a physical setting, various digital variants have emerged that can be played entirely online (Makri, Vlachopoulos and Martina 2021). The online playing of digital escape rooms usually alleviates the pressure of having to escape from the physical environment. Other mitigations are also conceivable, such as a lack of time pressure or less social presence of the participants. These restrictions presumably reduce the immersive experiences created by escape rooms. Nevertheless, the growing number of digital escape rooms suggests that valuable experiences are still achievable. Although digital escape rooms are unlikely to match the effectiveness of real-life escape rooms, there are several arguments in favour of using them. For example, the implementation costs are lower, there are no maintenance costs, it is simpler to adapt digital escape rooms than real escape room facilities and digital escape rooms are available to a much larger user base – users do not have to travel to the location just to play the escape room. Therefore, digital escape rooms can be seen as more accessible and have a raison d'être despite the loss of immersiveness. Admittedly, however, evaluations of digital educational escape rooms (DEER)

in particular are very rare to date (Fotaris and df Mastoras, 2019), as also described in the following section 2, the literature review. For example, in their systematic review of digital educational escape rooms, Makri, Vlachopoulos and Martina (2021) found the use of pre- and posttests to evaluate learning effectiveness in only 4 out of 45 studies. Accordingly, this study is aimed at contributing to the state of knowledge based on the investigation of a DEER that is particularly characterized by its low-threshold creation and low-threshold use. This raises the question of whether such a DEER, despite its low-threshold creation and low-threshold use and the resulting lower level of immersion, is still capable of achieving effective learning and favourable learner prerequisites. In addition, the user experience needs to be evaluated as a mission-critical factor due to the multiple browser tabs that require handling.

The basis of the DEER is a 360° room of a waterworks, through which students are sequentially guided by a web-based form containing, among other information, multiple choice questions (MCQs) as the escape room-specific puzzles. 360° room is here to be understood as composite ("stitched") panoramic shots from different viewpoints within the real object, which allow the object to be virtually walked through. The remainder of the article is structured as follows. In the next section 2, the state of the literature is described. As described in section 3.1, the goals of this single case study include a general clarification of the potential of low-threshold DEERs to promote student learning. The methods in this mixed-methods study, which are outlined in section 3.2, include a questionnaire as well as semi-structured interviews. In Section 4, the results are presented. In section 5 the results are discussed, and limitations described. In section 6, we conclude based on the data collected that low-threshold digital escape rooms constitute a promising educational tool.

2. Literature Review

Participation in escape rooms as a leisure activity has become very popular in recent years, resulting in an almost hundredfold increase in the number of escape room facilities in the U.S. from the years 2014 to 2020 (Spira, 2020). Accordingly, escape rooms are also increasingly appearing in the scientific literature (Krekhov *et al.*, 2021). For example, Nicholson (2015) presents an analysis on the types, structure, puzzles, and participants of escape rooms. Wiemker, Elumir and Clare (2015) similarly categorize escape rooms, for example, into competitive escape rooms, which allow competition between multiple teams, and score-based escape rooms, where team success is measured using metrics such as points. Krekhov et al. (2021) describe a categorization of the puzzles used in escape rooms. They distinguish primarily between *Mental Challenges*, such as knowledge, and *Physical Challenges*, such as self-motion and agility. Further, Krekhov et al. (2021) extend escape rooms from the real world to digital escape rooms, i.e., escape rooms that take place in digital environments, such as digital computer games or virtual reality environments. Accordingly, they complement the *Emotional Challenges* category, which is afforded by simulation in digital environments. For example, without real-world consequences eliminable through digital environments, difficult and moral decisions or fear- and disgust-inducing situations can be turned into escape room challenges. Hence, digital escape rooms broaden the application purposes for escape rooms, which might also be beyond entertainment. Wiemker, Elumir and Clare (2015) have previously pointed out further possible uses, for example, enhancing teamwork skills, or improving skills such as critical problem solving or critical thinking. In line with this, Cohen et al. (2020) positioned escape rooms as a medium to study teamwork. Furthermore, Terlouw et al. (2021) examined an escape room game for triggering social interactions between children with autism spectrum disorder and their peers.

Among the consistently mentioned purposes of escape rooms is education. Various terms are used in the literature, such as educational escape rooms (Martina and Göksen, 2022), educational escape games (Klamma *et al.*, 2020), escape rooms for learning (Fotaris and Mastoras, 2019), or escape room-based serious games (Terlouw *et al.*, 2021). Sanchez and Plumettaz-Sieber (2019) define educational escape rooms by five traits: In addition to the (1) physicality of a space, these include the aforementioned (2) clues and puzzles as well as (3) teamwork, also (4) fantasy and play, and especially (5) unambiguous educational objectives. Accordingly, the attributes of educational escape rooms are manifold. In the following a selection of prevalent characteristics is described.

2.1 Educational Contexts

Educational escape rooms are used in a variety of educational contexts, for example, in school (Ambrožová and Kaliba, 2021; Bezençon *et al.*, 2023) or in vocational education (Karageorgiou, Mavrommati and Fotaris, 2019). According to Fotaris and Mastoras (2019), over 70% of scientific studies take place in higher education – Makri et al. (2021) attribute this to higher education's predominant research context featuring extended resources.

2.2 Subject Areas

The subject areas in which educational escape rooms are used are also diverse, such as STEAM (Science, Technology, Engineering, Art and Mathematics) (Karageorgiou, Mavrommati and Fotaris, 2019; Sidekerskienė and Damaševičius, 2023), public health (Bezençon *et al.*, 2023), or entrepreneurship education (Martina and Göksen, 2022). Almost 30% of the studies identified by Fotaris and Mastoras (2019) involve health and welfare, followed by natural sciences, mathematics, and statistics (22%), social sciences, journalism and information (19%), and information and communication technologies (15%). Conversely, (Makri, Vlachopoulos and Martina, (2021) identify science, technology, engineering, and mathematics (STEM) as the most common subject areas.

2.3 (Digital) Media

Likewise, educational escape rooms are created using different media – hybrid and digital educational escape rooms are created using digital media, for example, web-based (Ambrožová and Kaliba, 2021), or mixed reality technologies-based (Klamma *et al.*, 2020), such as marker-based augmented reality (Buchner, 2023). Regarding digital escape rooms, it is worth noting that in the systematic literature review by Fotaris and Mastoras (2019), 77% of the studies were based on physical settings, whereas only 13% were in hybrid settings and only 10% were in digital settings.

2.4 Design Frameworks

Different design frameworks for educational escape rooms exist. For example, Eukel and Morrell (2021) recommend a 5-phase cyclical design process consisting of the design, pilot, evaluate, redesign, and re-evaluate phases. This design process is intended to promote deep, lasting learning experiences. Fotaris and Mastoras (2022) propose *Room2Educ8*, a student-centered framework following design-thinking principles. *Room2Educ8* has been developed for supporting various types of escape rooms as well as for a wide range of subject areas.

2.5 Authoring Systems

DEERs do not have to be coded from scratch; in fact, several authoring systems have already been developed. Commercial authoring systems include *Telescape Live* (Buzzshot, 2023), *Breakout EDU* (Breakout Inc., 2023), and *Room Escape Maker* (ROOM ESCAPE MAKER, 2023). Furthermore, open-source platforms exist for implementing DEERs, such as *Escapp* (GING, 2023), which also provide functionality for formal educational contexts, such as student registration, team formation, progress monitoring, hint management and monitoring (López-Pernas *et al.*, 2021). Additionally, multi-purpose platforms, such as *Google Slides* (Grāvelsiņa and Daniela, 2021) and *Google Forms* (Vergne, Smith and Bowen, 2020), that can be used for DEER creation, are worth mentioning.

2.6 Complexity of Implementation

Low technical and organizational complexity of implementation of DEERs promotes their use. For example, Vergne, Smith and Bowen (2020) use a web-based form containing MCQs. A similar approach exhibiting promising results was used by the authors Wehking et al. (2022). Such low-threshold approaches are linked to a reduction of the game character, soften the requirement for fantasy and play (Sanchez and Plumettaz-Sieber, 2019), and usually consist of a sequence of simple tasks (Ambrožová and Kaliba, 2021).

While in recent years the focus has been on the technical and organizational implementation of DEERs, and DEERs overall seem to fall into an early stage of development (Fotaris and Mastoras, 2022), design principles from the perspective of learning theories, instructional design, or learning psychology are rather underrepresented in the literature. Only a few studies mention learning theories as a foundation, such as generative learning (Karageorgiou, Mavrommati and Fotaris, 2019). From an instructional design perspective, Buchner, Rüter and Kerres, (2022) claim that playing an escape room following a conventional learning activity yields greater retention and domain-specific self-efficacy with lower cognitive load than the reverse order. Likewise, Pozo-Sánchez, Lampropoulos and López-Belmonte (2022) have investigated differences of face-to-face and online escape rooms: face-to-face escape rooms provide more entertainment to students and activate them better, while in online escape rooms students' autonomy, creativity and exploration were increased. Pozo-Sánchez, Lampropoulos and López-Belmonte (2022) conclude that choosing escape room variants depends on the goals to be achieved. Learning analytics, i.e., the analysis of data characterizing learning processes, is also helpful for optimization of DEERs. Accordingly, López-Pernas et al. (2022) identify various profiles of students using learning analytics that merit consideration in DEER design.

2.7 Systematic Literature Reviews

A general overview of the current state of educational escape rooms is provided in three systematic literature reviews by Fotaris and Mastoras (2019), Veldkamp et al. (2020), and (Makri, Vlachopoulos and Martina, (2021).

Among the major benefits of educational escape rooms are training of meta skills such as teamwork, collaboration, critical thinking, problem solving, leadership and creativity (Fotaris and Mastoras, 2019). Engagement and motivation were also mentioned in most studies. Learning outcomes were seen as a benefit, as was social interaction, in just under a third of the studies. The biggest challenges are the so far poor state of evaluation as well as the time commitment on the part of the lecturers for facilitating educational escape rooms. Nevertheless, it should be mentioned that most of the studies have investigated physical escape rooms and escape rooms that were conducted in the classroom. Veldkamp et al. (2020) exclude digital escape rooms in their review. Nevertheless, their call for aligning escape room objectives with learning objectives seems to be highly salient. In contrast, Makri et al. (2021) specifically examined escape rooms using digital technology in their systematic literature review. They, too, deplore the low degree of evaluations. However, (Makri, Vlachopoulos and Martina, (2021) pointed to the need for debriefings for promoting learning outcomes. In this claim, they are supported by Sanchez and Plumettaz-Sieber (2019). In contrast to Fotaris and Mastoras (2019), (Makri, Vlachopoulos and Martina, (2021) see cognitive skills as the most common learning goals. In line with the lack of evaluations and in line with the low evidence-based application of educational escape rooms, the study described in the following section contributes to bridging the gap, especially for educational escape rooms that can be created and applied in a low-threshold manner.

3. Study

3.1 Background

The genesis and research questions of the study are presented in this section. Waterworks are facilities of technical infrastructure. The functional principles of waterworks are part of the learning objectives in planning and engineering courses. Accordingly, a 360°-based walk-through visualization of a waterworks was used as part of a virtual field trip (Wolf et al., 2021). To create this visualization, 360° footage captured by a consumer camera (Insta360 ONE X) were stitched together to form a 360° room using *Matterport* software (Matterport Inc, 2020) and supplemented with text and graphic annotations (Figure 1 and Figure 2). In the following learning scenario, students were instructed to explore the waterworks freely, following the approach of exploratory learning (Freitas and Neumann, 2009). The only instruction given was to follow the flow of the water. An evaluation of this learning activity revealed high student acceptance and reported decent learning outcomes. However, some students reported feeling overwhelmed by the opportunity for free exploration and requested more guidance. Such guidance – inspired by guided learning, e.g., described in (Billett, 2000) and in (Leutner, 1993)– may be provided in a DEER through sequential tasks to be solved. Low-threshold DEERs have already been reported to be implementable using web-based forms with little technical effort (Vergne, Smith and Bowen, 2020). Accordingly, a web-based form was developed that is sequentially worked through and has the functions of conveying information and providing tasks consisting of MCQs.
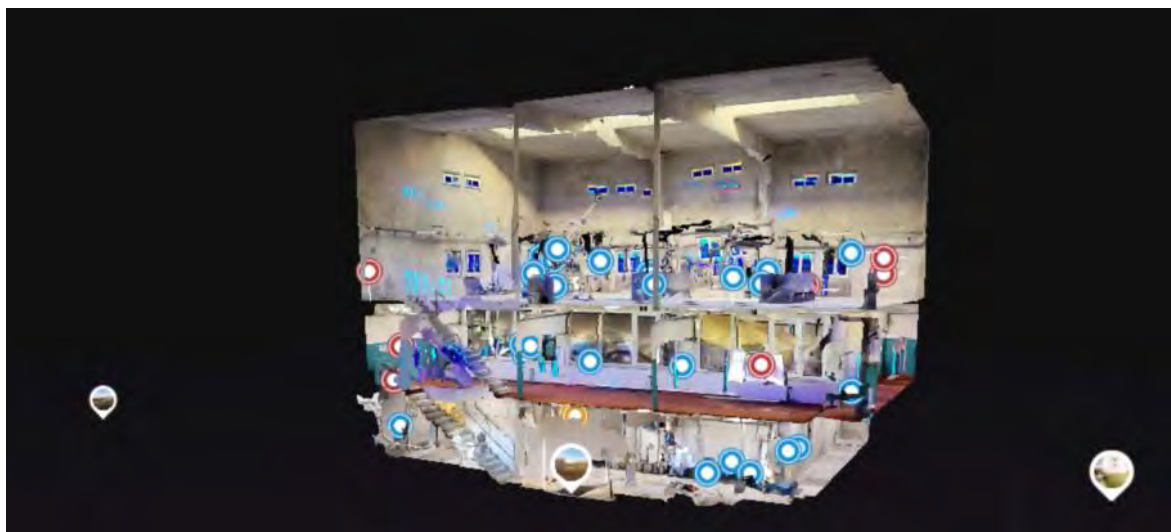

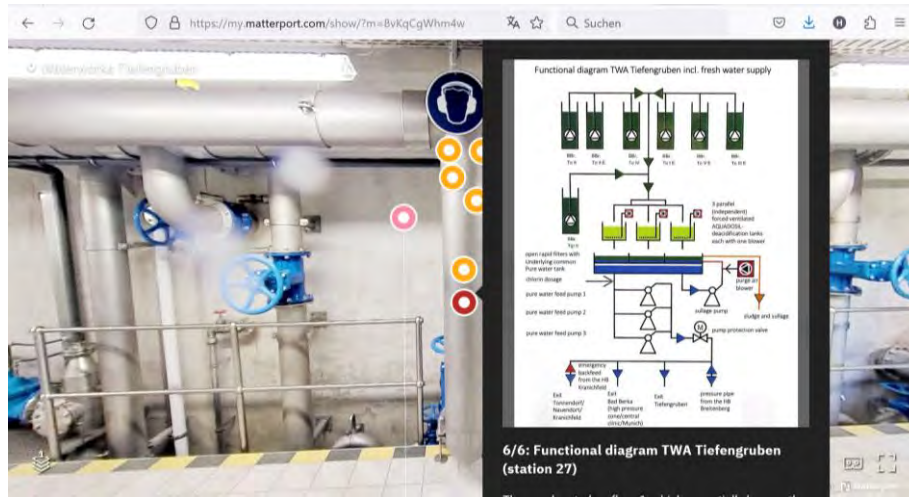**Figure 1: 360° room: Dollhouse View**

Figure 2: 360° room: Screenshot on the 1st floor showing an activated annotation

3.1.1   *Web-based form*

Google Forms was selected as the easy-access software providing web-based forms. To create the web-based form, the didactic concept that already existed for the annotations of the 360° visualization was extended. First, a schematic floor plan was developed for each of the three floors of the waterworks. The technical devices present on each floor, insofar as they also serve as points of interest (POI), were added to the floor plans. In addition, a sequence was developed in which the POIs were to be visited. A short instruction for students was then developed for each POI. The instruction describes the information to be acquired, e.g., using the form of text or graphic annotations, questions to be answered and gives a hint to the next POI to be visited. The questions correspond to the puzzles to be solved in an escape room. The question types used were single word questions and MCQs (Figure 3). The boss task, a task of higher complexity at the end, which is typical for an escape room, consists of a cloze text, which was also implemented using multiple MCQs.
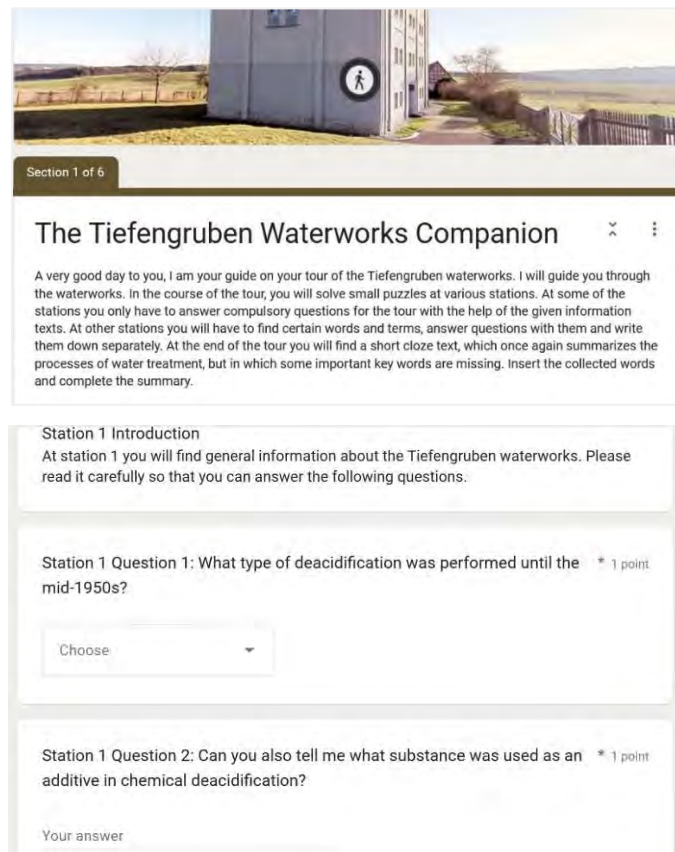

Figure 3: Introduction and sample questions of the web-based form

3.1.2   *Learning scenario*

The learning scenario included the 360° room and the Google Form. For both elements, the web link was given to the students with the instruction that they should individually explore the virtual waterworks, following the instructions and information provided in the Google Form. A potential time commitment of one hour was indicated. The exploration of the virtual waterworks was announced as a voluntary learning activity that supports the learning objectives of the respective course through the more practical knowledge of a field trip that can be attained via the DEER. Students had the chance to complete the DEER individually as part of a homework assignment over a 3-week period in the second half of each course. By answering 5 MCQs in the post-test, students were able to earn a maximum of 5 bonus points, which were applied to the written exam. These bonus points resulted in a high extrinsic motivation of students: When asked what impact the bonus points had in their decision to play through the escape room, a mean of M=4.1 (SD=0.9) was obtained on a 5-point Likert scale (1: no impact, I was solely interested in the waterworks and 5: I would not have been interested in the waterworks if I did not have the chance to gain bonus points).

The DEER described above, consisting of the 360° room visualization of the waterworks and the accompanying web-based form, was used in the learning scenario described and subjected to an evaluation study (Reinking and Alvermann, 2005). Alongside the general objectives of an evaluation study, such as analysing the effects of the intervention (Chang and Little, 2018), the following three research questions were examined in particular:

1. To what extent is the learning scenario accepted by students? (RQ1)
2. Are appropriate emotional and motivational learning prerequisites achieved? (RQ2)
3. Is an appropriate usability of the common handling of 360° visualization and web-based form achieved? (RQ3)

Answering these research questions is addressed by a mixed method study design using both qualitative and quantitative methods described below.

3.2   Methodology

3.2.1   *Study design*

The voluntary learning activity was presented to the students in a five-minute presentation by one of the researchers during a lecture. In addition to the educational added value to the course, the opportunity of earning bonus points and as well as the study embedding was presented. All information necessary was provided via the respective course room in the learning management system (LMS, Moodle). Contrary to the usual design of an escape room-based learning scenario, students were asked to complete the DEER individually, without a time limit and using non-immersive desktop VR on a notebook: one browser-window contained the web-based form and the 360° room was displayed in another window. The goal of that choice was to evaluate the guidance feature of the web-based form in a more isolated way, excluding group effects during the learning scenario. The first step of the study was a pretest consisting of 5 randomly selected MCQs from a pool of 15 MCQs about the waterworks. Then, students had the opportunity to accomplish the DEER. Finally, students participated in a post-test, which again consisted of 5 MCQs from the pool already used in the first step. Thereafter, the students were asked to answer a questionnaire. The questionnaire included demographic data, such as gender and age group. Furthermore, students were asked about their perceived prior knowledge and their perceived knowledge about the waterworks. The main parts of the questionnaire were three standardized research instruments. We looked at learning prerequisites, as these are particularly pertinent to the learning effectiveness of the DEER. As proxies for learning prerequisites, we specifically analysed emotion and motivation. The learner requirement motivation was assessed by the Questionnaire to Assess Current Motivation in Learning Situations (QCM) (Rheinberg, Vollmeyer and Burns, 2001). Further, emotions were measured by the Achievement Emotions Questionnaire (AEQ) (Pekrun *et al.*, 2011). Finally, the Questionnaire User Experience (QUX) (Müller, Heidig and Niegemann, 2012) was used to assess usability traits of the DEER. The QUX has been designed as a comprehensive assessment instrument for websites and records various categories of websites correspondingly. These categories include functional and non-functional qualities as well as emotions and an overall assessment. The variety of categories covered also implies the use of different scales by the QUS. Thus, the QUX uses 6-point Likert scales for rating functional qualities and a 10-point polarity profile for describing non-functional qualities of web-resources. Both, the 360° room and the web-based form are to be considered as web-resources rendering the QUX an appropriate measurement instrument. Lastly, 15 randomly selected participants were invited to a semi structured interview. The semi-structured interview was divided into the themes "General assessment", "Learning" and "Implementation". There were a total of 19 key questions, which were asked in the

interview depending on the flow of themes. Care was taken to ensure that all three themes were covered in each interview. The time frame for the interviews was 15 minutes, which was attained in all cases. In the end, 13 interviews conducted via videoconference were obtained. The interviews were transcribed by the two authors, who acted as interviewers, during the interview and were then subjected to qualitative analysis (Schmidt, 2004). Likewise, such qualitative analysis was applied to the answers to an open-ended question in the questionnaire, asking for participant's observations. In both cases, the qualitative analysis was conducted by two of the authors as reviewers using a spreadsheet software for documentation. Divergent findings were discussed to reach a common assessment. Informed consent was available for all participants.

Demographics. The learning scenario conducted in three different cohorts with N=76 participants (Table 1). 42 participants identified as male, 34 as female. In terms of age, the age groups were populated as follows: 18/19: 2, 20/21: 25, 22/23: 31, 24/25: 11, and 26/27: 4. Three participants reported being older than 27 years. Data from three participants was excluded due to incomplete datasets. The learning scenario was offered in two different courses, each of which included students from two undergraduate programs: one was 45 students in Urban Studies and the other was 30 students in Civil Engineering. In both courses, the learning scenario addresses the learning objective of providing an overview of the components and functioning of a waterworks.

Table: 1 Cohorts

Cohort #	Semester	Course	N
1	Winter Term 2021	Urban Water Management	16
3	Winter Term 2021	Urban Water Technology	28
5	Winter Term 2022	Urban Water Technology	32
		Sum	76

4. Results

4.1 Quantitative Findings

4.1.1 Learning outcomes

Participants reported a mean of 63.2 minutes when asked about the duration of the learning scenario (range: 20 - 120 minutes, SD: 23:28 minutes). There was no technical limit to the response time for the pre-test and post-test. The pretest averaged 8.11 out of a possible 10 points. On average, the students needed 16:35 minutes (range: 0:47 - 115:00 minutes, SD: 25:28 minutes). In the post-test, students improved to a mean of 9.47 (out of 10 points). The post-test took the students a mean of 7:18 minutes (range: 0:32 - 76:00 minutes, SD: 12:25 minutes). Students were able to score higher on the post-test in less than half the time. This learning outcome is more evident in the students' self-assessment. They selected on a 10-point scale their perceived knowledge before and after the learning scenario: while before the learning scenario knowledge was rated M=3.1 out of 10 points, after the learning scenario it was rated 6.8 out of 10 points. The levelling effect for the learning outcomes is also clear: the respective standard deviation decreases from SD=2.32 to SD=1.65. Several students needed more than one hour to complete the pre-test. This indicates that the pre-test might have been conducted in parallel with the exploration of the waterworks, contrary to the instructions. This practice might have led to an increase in points scored in the pre-test. The high scores obtained in the pre-test and post-test suggest that the questions might have been too simple and not very selective.

4.1.2 User experience

The QUX (Müller, Heidig and Niegemann, 2012) first assesses the functional qualities of the DEER (Figure 3). In general, the DEER is rated as sufficiently easy to understand (b) without the need for prior instruction (d) to learn the operation quickly (a), to develop confidence in the operation of the software (c), and to be able to work through the software well (e). Dropping in the students' evaluation are the statements that the information is easy to find (h) and the goal of using the software is easy to achieve (f) and the layout is clear (g). In our view, this constellation is to be interpreted as an indication that the handling of the software is simple and comprehensible, but also complicated in some parts. The rather low values point to the complexity of the task: the value of 3.2 for item (h) "The information I am looking for is easy to retrieve" is below the mathematical average of 3.5. The reason for this low value may be that there are no direct links into the 360° model for questions posed by the web-based form. Thus, learners must search, which sometimes requires time and effort.

Another reason for rather low scores may be the inconvenient handling of several web browser windows mentioned also in the qualitative results.
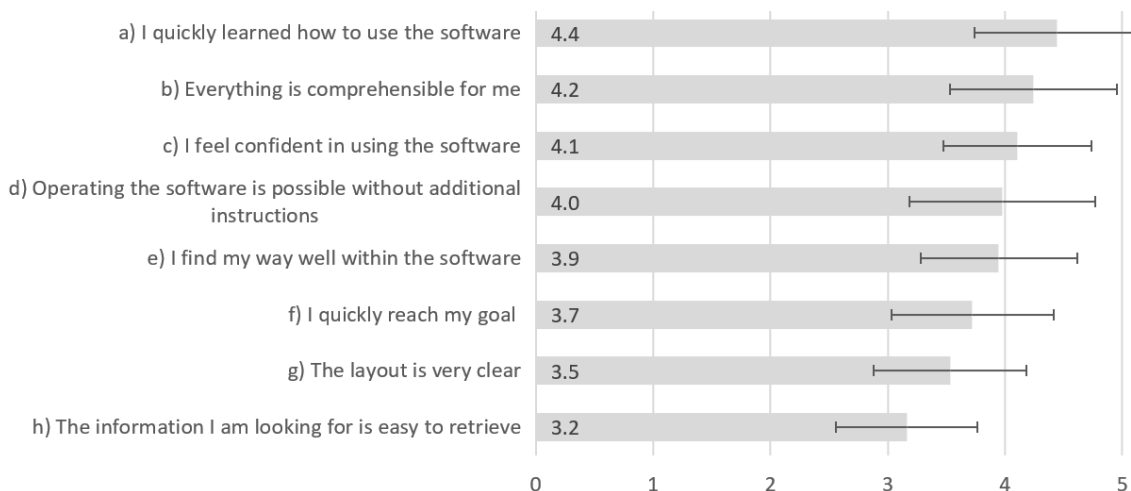

a) I quickly learned how to use the software	4.4
b) Everything is comprehensible for me	4.2
c) I feel confident in using the software	4.1
d) Operating the software is possible without additional instructions	4.0
e) I find my way well within the software	3.9
f) I quickly reach my goal	3.7
g) The layout is very clear	3.5
h) The information I am looking for is easy to retrieve	3.2

Figure 3: QUX: Functional Qualities (6-point Likert scale)

This assessment of inconvenient handling seems to be confirmed by the evaluation of the non-functional qualities (Figure 4). The poles such as convenient (k), activating (j), appealing (i) and aesthetic (h) are found at the lower end of the evaluation. The usefulness of the DEER per se is evidenced by high ratings for positive image (a), interesting (b), and creative (c). The attributes valuable (d), professional (e), thrilling (f), and attractive (g) are found in the rating midfield. The absolute differences of the ratings in the 10-point polarity profile are rather small, but these differences might also hint at the fact that the DEER is perceived rather positively in its core of virtual field trip and escape room, but that the handling is seen as less convenient.
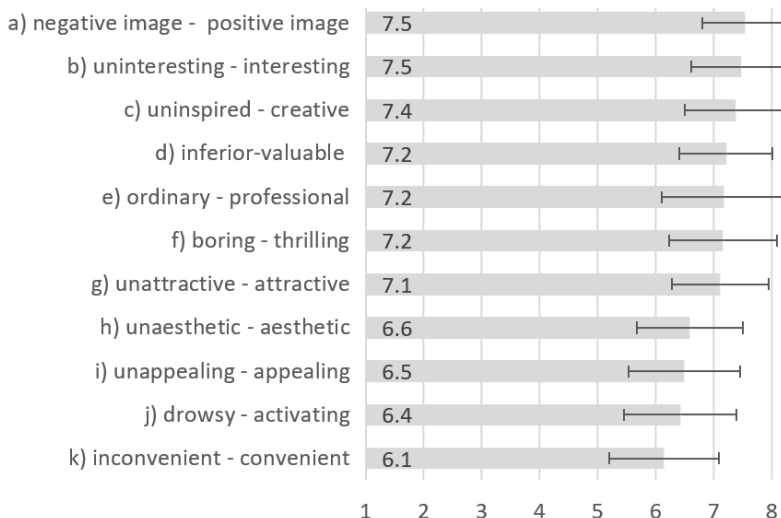

a) negative image - positive image	7.5
b) uninteresting - interesting	7.5
c) uninspired - creative	7.4
d) inferior-valuable	7.2
e) ordinary - professional	7.2
f) boring - thrilling	7.2
g) unattractive - attractive	7.1
h) unaesthetic - aesthetic	6.6
i) unappealing - appealing	6.5
j) drowsy - activating	6.4
k) inconvenient - convenient	6.1

Figure 4: QUX: Non-Functional Qualities (10-point polarity profile scale)

Further, with the QUX the overall impression by using four items is measured (Figure 5). Again, the usefulness of the DEER is recognized, with the intention to reuse is being rated highest (a) as well as the prospect of recommending it to others (b). Likewise, liking (c) and aesthetics (d) of the DEER are rated lower. As mentioned before, this might be interpreted as an indication of the previously already apparent non-optimal combination of 360° visualization and web-based form.
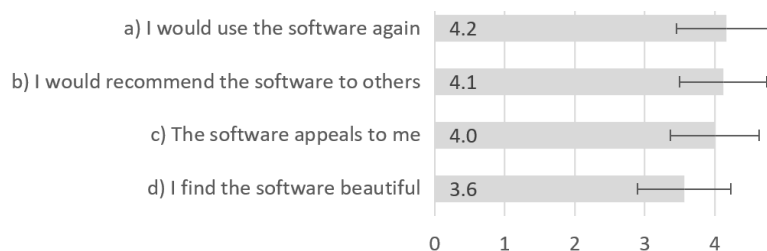
Figure 5: QUX: General statements (6-point Likert scale)

4.1.3 Emotions

Emotions are recognized as an important prerequisite for successful learning (Tyng *et al.*, 2017). Accordingly, emotions were assessed using the AEQ (Pekrun *et al.*, 2011). Here, the 8 specified sample items for learning related emotions were used (Pekrun *et al.*, 2011, p. 47) (Table 2). Notably, the emotions with positive connotations (Hope, Enjoyment, and Pride) received the highest scores. With Hope as the emotion rated at the highest, Hopelessness is correspondingly rated at the lowest. Shame and Boredom also receive low scores. The emotions with the highest negative connotations are Anger and Anxiety. This rating might be explained by the qualitative evaluation, in which reference is made to some puzzles that are difficult to solve. Overall, the emotions as measured by the AEQ are to be classified as conducive to learning, but the values for Anger and Anxiety, which are deemed to be elevated, should be kept in mind when revising the learning scenario. This assessment is also based on the emotion scores collected through the QUX (Table 2): Students report above average scores (3.5 on a 6-point Likert scale) for "I feel motivated" but only below average scores for "I feel fortunate" and "I feel happy."

Table 2: Emotions

Questionnaire	Emotion	M	SD
QUX	I feel motivated	3.9	1.16
(6-point Likert)	I feel fortunate	3.0	1.23
	I feel happy	3.0	1.14
AEQ	Hope	5.1	1.4
(7-point Likert)	Enjoyment	4.8	1.56
	Pride	4.1	1.69
	Anger	3.4	1.78
	Anxiety	2.8	1.7
	Boredom	2.4	1.61
	Shame	2.1	1.47
	Hopelessness	2.1	1.46

4.1.4 Motivation

Motivation is also regarded as one of the fundamental prerequisites for learning processes (Pintrich, 2003). Accordingly, the QCM (Rheinberg, Vollmeyer and Burns, 2001) was used to assess motivation (Figure 6). The results show a typical structure in the four subscales: Probability of Success (3.7), Interest (3.2) and Challenge (3.1) are above the mathematical mean of 3.0, while Anxiety (2.5) is below the mean. The high value for Probability of Success and the somewhat lower value for Challenge seem to indicate a manageable task. The value for Interest, which is barely above the mean, may reflect the high extrinsic motivation already observed due to the additional points. The low value of Anxiety, which is in fact high in comparison to other learning activities, (Rheinberg, Vollmeyer and Burns, 2001; Söbke, Arnold and Montag, 2020) could be affected through partial difficulty to solve tasks. Overall, the motivational situation does not seem to be detrimental to learning success but should likewise be kept in mind when revising the DEER.
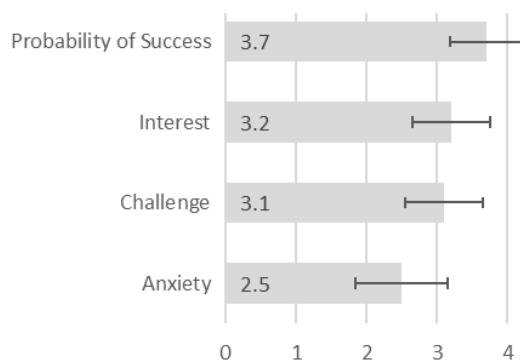
Figure 6: QCM: Subscales (5-point Likert scale)

4.2 Statistical Analysis

Apart from descriptive statistics, the study design did not include statistical analysis of the quantitative data as a primary goal. Nevertheless, it seems worthwhile analysing the data for incidental findings. Thus, within the statistical analysis, it is investigated whether differences exist regarding the acceptance of the DEER with respect to gender and the faculty to which the participants belong. T-tests were performed on the independent variables *Gender* (male vs. female) and *Course of Study* (Urban Studies vs. Civil Engineering) for all items of the QCM, AEQ and QUX. The effects found are presented in Table 3 and Table 4. Reported below are significant results at an alpha error level of 0.05 as well as results with an alpha error level between 0.05 and 0.1, which may be regarded as a tendency.

Gender. Although only small effects were found with respect to gender differences (table 3), some patterns are apparent. Female participants report a greater challenge on a motivational level, but also a higher interest than male participants. Females also rate the software more often as, e. g., valuable and activating. Also, more positive emotions are reported for *Enjoyment*, *Hope*, *Pride*, and *Boredom*.

Table 3: t-tests: Effects found for Gender (< 0.05 ("significant"), *<0.1 ("tendency)*)

Independent variable: **Gender**	female (n=41) M (SD)	male (n=34) M (SD)	
Interest (QCM)	3.342 (0.758)	2.953 (0.904)	t(73)=2.025, **p=.047**, d=0.231
Challenge (QCM)	3.213 (0.690)	2.735 (0.870)	t(73)=2.653, **p=.010**, d=0.297
Impressions: inferior-valuable (QUX)	7.610 (1.595)	6.740 (1.524)	t(73)=2.412, **p=.018**, d=0.272
Impressions: activating - drowsy (QUX)	3.900 (1.530)	5.380 (2.104)	t(73)=-3.521, **p=.001**, d=0.381
Impressions: creative - uninspired (QUX)	3.290 (1.834)	4.000 (1.651)	t(73)=-1.739, *p=.086*, d=0.199
Impressions: uninteresting - interesting (QUX)	7.880 (1.400)	7.000 (1.985)	t(73)=2.240, **p=.028**, d=0.254
Impressions: unappealing - appealing (QUX)	6.850 (2.019)	6.060 (1.757)	t(73)=1.799, *p=.076*, d=0.206
Functionality: The layout is very clear (QUX)	3.290 (1.436)	3.820 (1.086)	t(73)=-1.774, *p=.080*, d=0.203
Enjoyment: I enjoy acquiring new knowledge (AEQ)	5.200 (1.308)	4.350 (1.756)	t(73)=2.314, **p=.024**, d=0.286
Hope: I have an optimistic view toward studying (AEQ)	5.370 (1.299)	4.710 (1.467)	t(73)=2.065, **p=.042**, d=0.235
Pride: I'm proud of my capacity (AEQ)	4.460 (1.675)	3.710 (1.661)	t(73)=1.957, *p=.054*, d=0.223
Boredom: The material bores me to death (AEQ)	1.900 (1.241)	3.090 (1.798)	t(56.891)=-3.255, **p=.002**, d=0.396

Faculty. Regarding the course of study to which the participants belong, some small effects and tendencies can also be identified. Civil Engineering students report that they are happier with the software, and they also find it more thrilling and appealing than architecture and urban studies students. It could be argued that Urban Studies students are more demanding in terms of the aesthetical design of the environment, while Civil Engineering students focus more on the function and facts. The differences could also reflect that the

waterworks contains some technical details that are more relevant to Civil Engineering students. This could, for example, explain the higher Interest (QCM) of Civil Engineering students. For the items of the AEQ, on the other hand, no differences were found between the two courses of study.

Table 4: t-tests: Effects found for Faculty (CE = Civil Engineering, US= Urban Studies, < 0.05 ("significant"), <0.1 ("tendency))

Independent variable: **Course of Study**	CE (n=30) M (SD)	US (n=44) M (SD)	
Interest (QCM)	3.353 (0.838)	3.023 (0.836)	t(72)=1.669, *p=.099*, d=0.193
Emotion: Happy (QUX)	3.270 (1.081)	2.730 (1.149)	t(72)=2.031, **p=.046**, d=0.233
Impressions: thrilling - boring (QUX)	3.170 (1.704)	4.250 (1.882)	t(72)=-2.525, **p=.014**, d=0.285
Impressions: creates a positive image - creates a negative image (QUX)	3.000 (1.339)	3.770 (1.492)	t(72)=-2.278, **p=.026**, d=0.259
Impressions: unappealing - appealing (QUX)	7.000 (2.117)	6.160 (1.765)	t(72)=1.855, *p=.068*, d=0.214
Impressions: aesthetic - unaesthetic (QUX)	3.500 (1.570)	5.050 (1.791)	t(72)=-3.827, **p=.000**, d=0.411
Functionality: The layout is very clear (QUX)	3.930 (1.112)	3.250 (1.383)	t(72)=2.253, **p=.027**, d=0.257
General: The software appeals to me (QUX)	4.370 (1.098)	3.750 (1.349)	t(72)=2.077, **p=.041**, d=0.238
General: I would use the software again (QUX)	4.600 (1.276)	3.840 (1.462)	t(72)=2.307, **p=.024**, d=0.262
General: I find the software beautiful (QUX)	4.170 (1.206)	3.110 (1.280)	t(72)=3.556, **p=.001**, d=0.387
General: I would recommend the software to others (QUX)	4.570 (1.104)	3.800 (1.268)	t(72)=2.703, **p=.009**, d=0.304

Although individual effects were detected by statistical analysis, they do not yet provide a clear overall picture. In further work, such effects need to be identified, e.g., by using learning analytics, so that they might be constructively incorporated into the design of DEERs.

4.3 Qualitative Findings

Participants were able to express their own thoughts about the learning scenario within an open-ended question asked in the questionnaire. In addition, semi-structured interviews were conducted after the completion of the learning scenario. Prominently mentioned topics of the questionnaire were also included in the semi-structured interview.

4.3.1 Questionnaire

In the questionnaire, the participants were asked in a concluding open question about further impressions of the learning scenario. A total of 39 participants responded here, to which 77 codes were assigned. Multiple responses are indicated below. In cluster **(1) General Impression**, the learning activity was assessed as positive a total of 14 times; there was one negative assessment. In cluster **(2) Characterization**, general statements about the learning scenario were gathered. The statements included that the learning scenario achieved a level of authenticity that is only surpassed by real-life environments (4 times). The learning activity was also characterized as fun (3 times). An alternative way of teaching was mentioned twice. The possibility of the self-directed learning at one's own pace was praised. Contradictory were the statements that a learning experience was missing and on the other hand that the 360° room had created such a high immersion level that the web-based form had been forgotten. Regarding the **(3) Didactic Scenario**, the bonus points for the exam were mentioned positively (2 times). It was desired to make the presentation of the learning activity in the LMS clearer (2 times) and there was a complaint about not communicating the limited processing period sufficiently. Among the **(4) Design Details**, the site map and the web-based form were praised 2 times each. The built-in video annotations were equally mentioned as positive. In the cluster **(5) Usability** problems were mainly collected. For example, the operation of the floor selector of the 360° room is not intuitive (3 times). Two times each, the usage on a tablet or cell phone was mentioned as challenging as well as the unrecognized scroll option of text

annotations. Other mentions include the challenging handling of the browser windows, the difficulty in getting to the exterior views of the 360° rooms, the generally non-intuitive operation, the overview of floor plans that could be improved, and very small text fields. Among the **(6) Problems** encountered the incorrect word puzzle dominated (16 times). In addition, 2 comments pointed out that the 360° room could not be displayed at all for certain tablets or smartphones. Several **(7) Improvements** were also suggested. Three times the linking of the stations to be visited in a certain order was suggested. Two times the variant of visually highlighting the next station was mentioned. More video annotations showing explanations by staff members were also mentioned (2 times). Other requests for improvement include a progress bar, audio loops and the integration of floor plans.

4.3.2   *Semi-structured interviews*

Interviews were conducted with 13 participants, which are abbreviated in the following as I1 to I13. The semi-structured interviews were conducted by two researchers. The guiding questions were divided into three themes. The theme **General Impression** asked about the overarching impression regarding the learning scenario and whether re-participation in a similar learning scenario would be likely. The theme **Learning** was hardly represented in the answers to the open question of the questionnaire. Accordingly, it was asked to what extent the interviewees considered the learning scenario to be conducive to learning and how the learning scenario contributed to a stronger understanding of water processing. Likewise, interviewees were asked about the appropriateness of the learning content and about a comparison with conventional methods. In the Theme **Delivery**, details of the delivery of the learning activity were addressed, such as how often the tour was walked, what technical challenges were encountered, and to what extent the guidance and navigation was clear.

In the qualitative analysis of the interview data, a total of 272 statements were categorized and clustered. All statements with at least 3 mentions are presented below. In the theme **General Impression**, all 13 interviewees reported a positive overall impression and a very successful learning activity, and all would participate in a similar learning activity again. The sound structure was lauded (3 times), which led to a sound impression of the waterworks as the process (4 times). Three interviewees named it helpful seeing the theoretical knowledge in practice. The letter search was mentioned negatively 7 times, while 6 times the quality of the 360° room and the guidance through the web-based form were complimented.

In the theme **Learning**, the cluster *Appropriateness* is found. 6 interviewees perceived the content to be appropriate, while 4 urban studies participants categorized the content as too comprehensive. Likewise, the order of the stations was found to be reasonable, and the annotations were marked as comprehensible. In the *Replacement for Field Trips* cluster, only partial replacement was confirmed by 7 interviewees. The success of the learning scenario was reported by a total of 6 respondents, ranging from 60 to 120% of a real field trip. Also, six times the learning activity was suggested as a supplement to a real field trip, for example as a follow-up. The lack of opportunity for follow-up questions was mentioned seven times as a significant learning-relevant difference to a field trip. In the *Knowledge Acquisition* cluster, 6 interviewees stated that they had learned new knowledge, in contrast to 5 interviewees who rather emphasized the consolidation of basic knowledge learned in lectures. The appropriateness of the learning scenario for students who prefer visual information was emphasized by 5 interviewees. Remarkable is the statement of 4 interviewees that interpersonal contacts were missed. On the other hand, the opportunity for self-directed learning was mentioned positively 6 times.

In the theme of **Delivery**, initial difficulties in operation were expressed three times. When asked about the number of iterations through the 360° room, 9 of the interviewees stated having carried out the process exactly once. In contrast, 3 interviewees stated that they had iterated back and forth several times. Likewise, 3 interviewees expressed that they had jumped back specifically to look up details when needed. In the *Suggestions for Improvement* cluster, the videos already mentioned in the written survey including those of technical processes (9 times) were mentioned. Four interviewees would like to see a tutorial that cannot be skipped, while 3 times it was requested that the POIs in the 360° room have the same numbering as in the web-based form. Three times the permanent provision of the learning scenario was requested to enable learning outside of bonus points.

The interviews addressed the learning scenario as a whole and did not ask about specific components, as the functionality of the learning scenario was to be explored. Nevertheless, the web-based form is the implementation of the escape room metaphor. Accordingly, the few statements about the web-based form will be reproduced here. Two interviewees stated that they first started to explore the 360° room on their own and then used the web-based form to walk the 360° room systematically. Once – as in the questionnaire – it was pointed out that the web-based form opened in a different browser tab was forgotten during the exploration of

the 360° room. Two other interviewees complained that the web-based form was not intuitive. The text-heavy nature of the web-based form was also mentioned, and more graphics were requested.

4.3.3 Selected statements

For providing a more profound impression of the qualitative results some quotes from the interviews that may be considered representative to characterize the learning scenario are presented. The advantages of the learning activity were clearly elaborated by some interviewees. Accordingly, I13 praises the self-directed learning scenario:

> *"In addition, you then engage more intensively with things yourself and are then also more attentive or have a longer attention span than as in a long monologue."*

I9 summarizes the learning outcomes, the connection with visual orientation, and the appropriateness of information granularity as follows:

> *"I definitely understood the structure [of the waterworks] and how water is treated much better. The direct visual images help me to learn, and I can now directly understand different terms because I have a picture in mind. Some of the information was very detailed, but I felt it was not too much."*

Both in the adequacy of the information and in the visualization, I13 concurs:

> *"The information was summarized briefly, so it was pleasant to be able to comprehend it, I wouldn't say too detailed - especially the drawings and videos made the processes more comprehensible."*

Regarding the learning successes, I9 comments that it is not so much the concrete factual knowledge that was remembered, but.

> *"It's more the pictures - that if I heard the name now, I could directly relate to."*

In this context, answers to the questions asked in some interviews about specifically remembered details also seem to be interesting. For example, the darkened windows on the third floor were mentioned a total of 4 times, and the filter basins were mentioned twice - each visually impressive details of the waterworks. Referring to the web-based form, I11 expressed that this was…

> *"… not essential to the exercise if students feel like exploring."*

This utterance coincides with the reason for using the web-based form as a motivating and guiding element and shows that the learning activity may be done optionally with or without the web-based form – the escape room metaphor. I5 indicates the importance of good usability for learning success:

> *"[I failed] but miserably […] to get to the top floor and then after 7 min I found out that you can also change floors on a button at the bottom left and this also worked. Anyway, after that I was so annoyed that I didn't remember anything. The too-small info cards then added the rest to my emotional pomposity, so little stuck technically."*

The fact that the learning activity was honoured by the students despite all the introductory problems is summarized by I12 in a concluding wish:

> "*That they keep working [on such learning scenarios] and spread it among the student body that we have such projects at the university*."

5. Discussion

Overall, both the quantitative and qualitative results reveal a learning scenario that is accepted and considered valuable by the students. The quantitative results document the learning conduciveness of the learning scenario regarding the learning prerequisites emotion and motivation. The technical setting of 360° room and web-based form can be attributed to sufficient usability. The qualitative results especially show a high basal satisfaction with the learning scenario. In particular, the unique selling points in comparison with conventional learning activities are also highlighted, such as the visual presentation and the opportunity for exploration. However, on this sound starting point, several areas for optimization that need to be addressed in the next iterations of the DEER were identified. They are mentioned below:

5.1 Predominance of the 360° Room

Especially in the qualitative studies, the 360° room was the focus of comments. The web-based form was mentioned much less, it seemed to integrate inconspicuously into the learning activity. The inconspicuousness was probably favoured by the low-profile framing of the web-based form as a companion. To justify framing it as an escape room with challenging and fun-generating game mechanics and thus reduce the dominance of the 360° room, game mechanics, in this case especially the puzzles to be solved, must be valorised. Measures to balances this prevalence include the integration of the 360° room with a digital world, such as WorkAdventure (WorkAdventure, 2023). It is also conceivable to use a digital escape room framework, such as Telescape Live (Buzzshot, 2023). However, the extent to which the technical and organizational low threshold is maintained must be taken into consideration.

5.2 Detailing Didactic Information

Especially, urban studies students indicated that the level of detail of the learning activity information was too fine-grained. While the use of target group-specific didactic skins was previously suggested for the 360° space (Wolf et al., 2021), it makes sense to develop separate web-based forms for each of the different target groups, whether subject-specific or degree-specific (Master vs. Bachelor).

5.3 Low Scores for Learning Prerequisites

The scores for learning requirements (here: usability, emotion, and motivation) are consistently lower than those of previously studied learning activities (e.g., (Wolf et al., 2021a, 2021b). From our point of view, these reduced values do not question the design of the learning activity, but rather are explained multifactorial:

4. The learning scenario in this study was completed by each student individually. This is to be seen as a major deviation from the escape room metaphor. However, we took this deviation into account particularly to focus the study on the two technical foundations of the learning activity (360° room and web-based form). The intended implementation of the learning scenario in groups will likely, following the principles of situational learning (Lave and Wenger, 1991), lead to a reduction of emerging difficulties and have a positive effect on the learning prerequisites.
5. Handling the software with two different web browser tabs is rather inconvenient for single-screen devices, such as smartphones, tablets, and notebooks. This could probably be counteracted with the integration of 360° room and web-based form.
6. The flaws in various word puzzles, which were only fixed in the later cohorts, certainly contributed to irritation, and reduced the measured values. These effects should no longer occur now.

5.4 GDPR Compliance

In the learning scenario, Google Forms was used as a web-based form for prototyping purposes. Google Forms is viewed critically from a data protection perspective in Germany. Therefore, an alternative has yet to be found for regular operation in teaching.

5.5 Future Work

An essential result of the study is the limited usability resulting from two different web browser tabs. An integrated solution that combines the puzzle tasks and 360° room in one space is to be striven for. At the same time, the strength of the DEER's ease of implementation should not be sacrificed for such an integrated solution. Thus, we are currently preparing a DEER using the low-threshold collaboration environment WorkAdventure (WorkAdventure, 2023). On the one hand, this will enable the integration of guidance, tasks, and the spatial environment. On the other hand, it is feasible for each learner to be represented by an avatar in the environment, presumably strengthening social presence and enabling embodiment effects. Another aspect that is to be strengthened in future is the tasks to be solved. At present, they are largely based on multiple-choice questions with limited entertainment value. Consequently, the game character of the escape room is neglected. An approach to a solution is the use of gamification mechanisms that also utilise the spatial dimension of the DEER (Das *et al.*, 2022). For example, one task could be to ask learners to navigate to a specific location in the DEER and thus train spatial expertise.

Furthermore, we consider a taxonomy of escape rooms missing that might assist to delineate escape rooms between the poles of "entirely in a physical, enclosed space" and "entirely digital using an electronic device". Any such taxonomy, which also includes other design features such as the involvement of facilitators, game, and

puzzle mechanics, multiple or single users, would be extremely beneficial in categorizing the numerous escape rooms that are available.

5.6 Limitations

Certainly, the study also shows some limitations, which will be described in the following.

7. **Pre- and Post-Test.** The questions of the pre- and post-test turned out to be insufficiently selective, so that a ceiling effect could be observed. Nevertheless, the learning effectiveness of the DEER was demonstrated. Similarly, pre-test and post-test lacked a time limit. It is likely that the pretest was taken by some students during the learning scenario and indicated increased scores for actual prior knowledge. Furthermore, it was possible that due to the pool of questions, some participants could receive the same questions in the post-test as in the pre-test. However, a potentially confounding effect is reduced by only posing 5 questions from the pool of 15 questions at any one test. In addition, the correct answers in the pre-test were not disclosed. In future studies, the pre-test and post-test should consist of two separate sets of questions.

8. **Adoption of Evaluation Instruments.** The evaluation instruments were used in a moderately modified manner, as described in the following. The QUX (Müller, Heidig and Niegemann, 2012) for determining usability was developed specifically for evaluating websites. This is fitting here, as both components of the learning activity (360° room and web-based form) are operated as websites. A limitation could arise from the nature of the learning scenario. The recommendation for the QCM is to employ it before the learning scenario. For simplification reasons (only one questionnaire), the QCM data was collected following the learning scenario. Nevertheless, to maintain validity, students were asked to refer to a similar learning scenario yet to be completed when answering. Furthermore, a 7-point Likert scale was used for the AEQ, which was originally designed based on a 5-point Likert scale. Likewise, the QCM, which was validated for a 7-point scale, was used with a 5-point scale. (Dawes, 2008), though, succeeded in showing that 5- and 7-point Likert scales produce highly similar scores. Irritation could be caused by the different scales of the QUX 6-point Likert scales and 10-point polarity profile, which, however, were used in this study in the validated form. Overall, there is a debate about when to employ Likert scales with (such as 6 point) or without midpoint (such as 5 or 7 point) (Chomeya, 2010; Chyung *et al.*, 2017). In general, however, we believe that the adapted use of the scales yielded valid results given the evaluative character of the study.

9. **Bias due to quasi-voluntariness.** The learning scenario was not mandatory. Only students who voluntarily participated in the learning activity were surveyed. Admittedly, voluntariness was constrained by the bonus points attainable for the exam. Presumably, voluntariness is to be seen as having a measurement-improving effect.

6. Conclusion

Web-based forms offer a simple, technical, and organizational low-threshold option for converting 360° rooms into digital educational escape rooms (DEERs). Intended effects are increased motivation and guidance through the 360° room. Guidance has been suggested by some students who feel overwhelmed by the free exploration of 360° rooms. To date, however, such approaches have not been described in the literature. Accordingly, in this study, an existing 360° room was extended into a DEER using a web-based form and made to be applied in undergraduate courses. The application was conducted using pre- and post-tests to evaluate learning outcomes, a questionnaire to determine learning prerequisites (emotion, motivation, and usability), and semi structured interviews to qualitatively assess additional aspects. The results substantiate learning outcomes, suitable learning prerequisites (RQ2), a decent usability of the DEER (RQ3) and acceptance by students as an alternative learning scenario (RQ1). Among the noteworthy advantages is self-directed learning at one's own pace, while the lack of opportunity to interact with guides was claimed to be disadvantageous. The study also identified several potential improvements, which are now being successively implemented. At least for a good part of the students, a web-based form is an aid for guiding them through the 360° room. Together with the variant including no web-based form, students can be offered a choice depending on their own preferences. However, there is still work necessary to deepen the playful escape room character, while maintaining the technical and organizational low-threshold accessibility. Overall, the study demonstrated that complementing a 360° room with a web-based form can provide a low-threshold accessible DEER as foundation of a productive learning scenario. Thus, the present study contributes to the further variation of learning scenarios based on 360° rooms and expands the corpus of empirical evidence of DEER applications.

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